

Dark matter from stable charged particles?

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February 2, 2008

Abstract

Particle physics candidates for cosmological dark matter are usually considered as neutral and weakly interacting. However stable charged leptons and quarks can also exist and, hidden in elusive atoms, play the role of dark matter. The necessary condition for such scenario is absence of stable particles with charge -1 and effective mechanism for suppression of free positively charged heavy species. These conditions are realized in several recently developed scenarios. In scenario based on Walking Technicolor model excess of stable particles with charge -2 and the corresponding dark matter density is naturally related with the value and sign of cosmological baryon asymmetry. The excessive charged particles are bound with primordial helium in techni-O-helium "atoms", maintaining specific nuclear-interacting form of dark matter. Some properties of techni-O-helium Universe are discussed.

1 Introduction

The modern theory of Universe, based on General Relativity, has evolved the triumph of Einstein's ideas by putting cosmological term, first introduced by A.Einstein in 1917 [1], in the "standard" Λ CDM model. The corresponding dark energy is the dominant element of the modern Universe, maintaining 70% of its total density.

General Relativity and Dark Energy maintain the frame for the portrait of elementary particles in the Universe. To survive in the Universe the particles should be stable, as are nuclei and electrons, composing the visible

matter. However, one must also explain the modern dark matter density, corresponding to 25% of total density and exceeding the baryonic matter density by a factor of 5. The widely shared belief is that dark matter is nonbaryonic and consists of new stable particles.

For a particle with the mass m the particle physics time scale is $t \sim 1/m$ (here and further, if not indicated otherwise, we use the units $\hbar = c = k = 1$), so in particle world we refer to particles with lifetime $\tau \gg 1/m$ as to metastable. To be of cosmological significance metastable particle should survive after the temperature of the Universe T fell down below $T \sim m$, what means that the particle lifetime should exceed $t \sim (m_{Pl}/m) \cdot (1/m)$. Such a long lifetime should find reason in the existence of an (approximate) symmetry. From this viewpoint, cosmology of dark matter is sensitive to the most fundamental properties of microworld, to the conservation laws reflecting strict or nearly strict symmetries of particle theory.

One can formulate the set of conditions under which new particles can be considered as candidates to dark matter (see e.g. [2, 3, 4, 5] for review and reference).

- The particles should be stable or have lifetime larger, than age of the Universe.
- They should fit the measured density of dark matter. Effects of their decay or annihilation should be compatible with the observed fluxes of electromagnetic background radiation and cosmic rays.
- More complicated forms of scalar fields, primordial black holes and even evolved primordial large scale structures are also possible, but in the latter case the contribution to the total density is restricted by the condition of the observed homogeneity and isotropy of the Universe
- The candidates for dark matter should decouple from plasma and radiation at least before the beginning of matter dominated stage. This is necessary to provide formation of large scale structure at the observed level of anisotropy of the cosmic microwave background radiation.

The easiest way to satisfy these conditions is to involve neutral weakly interacting particles. However it is not the only particle physics solution for the dark matter problem. As we show here, new stable particles can have electric charge, but effectively behave as neutral and sufficiently weakly interacting.

Recently several elementary particle frames for heavy stable charged particles were proposed:

- (a) A heavy quark and heavy neutral lepton (neutrino with mass above half the Z-Boson mass) of fourth generation [6, 7]; which can avoid experimental constraints [8, 9] and form composite dark matter species [10, 11, 12, 13];
- (b) A Glashow’s “sinister” heavy tera-quark U and tera-electron E , which can form a tower of tera-hadronic and tera-atomic bound states with “tera-helium atoms” ($UUUEE$) considered as dominant dark matter [14, 15].
- (c) AC-leptons, predicted in the extension [16] of standard model, based on the approach of almost-commutative geometry [17], can form evanescent AC-atoms, playing the role of dark matter [16, 18, 19, 13].

Finally, it was recently shown in [20] that an elegant solution is possible in the framework of walking technicolor models [21, 22, 23, 24, 25, 26] and can be realized without an *ad hoc* assumption on charged particle excess, made in the approaches (a)-(c).

In all these models, predicting stable charged particles, the particles escape experimental discovery, because they are hidden in elusive atoms, maintaining dark matter of the modern Universe. It offers new solution for the physical nature of the cosmological dark matter.

This approach differs from the idea of dark matter, composed of primordial bound systems of super heavy charged particles and antiparticles, proposed earlier to explain the origin of Ultra High Energy Cosmic Rays (UHECR) [27]. To survive to the present time and to be simultaneously the source of UHECR super heavy particles should satisfy a set of constraints, which in particular exclude the possibility that they possess gauge charges of the standard model.

The particles, considered here, participate in the standard model interactions and we discuss the problems, related with various scenarios of composite atom-like dark matter, formed by heavy electrically charged stable particles.

2 Charged components of composite dark matter

2.1 Charged tera-particles

In Glashow’s “Sinister” $SU(3)_c \times SU(2) \times SU(2)' \times U(1)$ gauge model [14] three heavy generations of tera-fermions are related with the light fermions by CP' transformation linking light fermions to charge conjugates of their

heavy partners and vice versa. CP' symmetry breaking makes tera-fermions much heavier than their light partners. Tera-fermion mass pattern is the same as for light generations, but all the masses are multiplied by the same factor $\sim 10^6$. It gives the masses of lightest heavy particles in *tera*-eV (TeV) range, explaining their name. Strict conservation of $F = (B - L) - (B' - L')$ prevents mixing of charged tera-fermions with light quarks and leptons. Tera-fermions are sterile relative to $SU(2)$ electroweak interaction, and do not contribute into standard model parameters. In such realization the new heavy neutrinos (N_i) acquire large masses and their mixing with light neutrinos ν provides a "see-saw" mechanism of light neutrino Dirac mass generation. Here in a Sinister model the heavy neutrino is unstable. On the contrary in this scheme E^- is the lightest heavy fermion and it is absolutely stable.

Since the lightest quark U of heavy generation does not mix with quarks of 3 light generation, it can decay only to heavy generation leptons owing to GUT-type interactions, what makes it sufficiently long living. If its lifetime exceeds the age of the Universe, primordial U -quark hadrons as well as heavy leptons E^- should be present in the modern matter.

Glashow's "Sinister" scenario [14] took into account that very heavy quarks Q (or antiquarks \bar{Q}) can form bound states with other heavy quarks (or antiquarks) due to their Coulomb-like QCD attraction, and the binding energy of these states substantially exceeds the binding energy of QCD confinement. Then (QQq) and (QQQ) baryons can exist.

According to [14] primordial heavy quark U and heavy electron E are stable and may form a neutral most probable and stable (while being evanescent) $(UUUEE)$ "atom" with (UUU) hadron as nucleus and two E^- s as "electrons". The tera gas of such "atoms" seemed an ideal candidate for a very new and fascinating WIMP-like dark matter.

2.2 Stable AC leptons from almost commutative geometry

The AC-model [16] appeared as realistic elementary particle model, based on the specific approach of [17] to unify general relativity, quantum mechanics and gauge symmetry.

This realization naturally embeds the Standard model, both reproducing its gauge symmetry and Higgs mechanism, but to be realistic, it should go beyond the standard model and offer candidates for dark matter. Postulates of noncommutative geometry put severe constraints on the gauge symmetry group, excluding in this approach, supersymmetric and GUT extensions as well as the extensive phenomenology of superstrings. The AC-model [16]

extends the fermion content of the Standard model by two heavy particles with opposite electromagnetic and Z-boson charges. Having no other gauge charges of Standard model, these particles (AC-fermions) behave as heavy stable leptons with charges $-2e$ and $+2e$, called here A and C , respectively. AC-fermions are sterile relative to $SU(2)$ electro-weak interaction, and do not contribute to the standard model parameters. The mass of AC-fermions is originated from noncommutative geometry of the internal space (thus being much less than the Planck scale) and is not related to the Higgs mechanism. The lower limit (≥ 100 GeV) for this mass follows from absence of new charged leptons in LEP. In the absence of AC-fermion mixing with light fermions, AC-fermions can be absolutely stable.

The mechanism of baryosynthesis in the present version of AC model is not clear, therefore the AC-lepton excess was postulated in [16, 18, 19] to saturate the modern CDM density (similar to the approach sinister model). Primordial excessive negatively charged A^{--} and positively charged C^{++} form a neutral most probable and stable (while being evanescent) (AC) "atom", the AC-gas of such "atoms" being a candidate for dark matter, accompanied by small ($\sim 10^{-8}$) fraction of ${}^4HeA^{--}$ atoms called in this case OLe-helium [16, 18, 19, 13].

2.3 Stable pieces of 4th generation matter

Precision data on Standard model parameters admit [9] the existence of 4th generation, if 4th neutrino (N) has mass about 50 GeV, while masses of other 4th generation particles are close to their experimental lower limits, being > 100 GeV for charged lepton (E) and > 300 GeV for 4th generation U and D quarks [28].

4th generation can follow from heterotic string phenomenology and its difference from the three known light generations can be explained by a new conserved charge, possessed only by its quarks and leptons [6, 8, 10]. Strict conservation of this charge makes the lightest particle of 4th family (4th neutrino N) absolutely stable, while the lightest quark must be sufficiently long living [8, 10]. The lifetime of U can exceed the age of the Universe, as it was revealed in [8, 10] for $m_U < m_D$.

U -quark can form lightest (Uud) baryon and ($U\bar{u}$) meson. The corresponding antiparticles are formed by \bar{U} with light quarks and antiquarks. Owing to large chromo-Coulomb binding energy ($\propto \alpha_c^2 \cdot m_U$, where α_c is the QCD constant) stable double and triple U bound states (UUq), (UUU) and their antiparticles ($\bar{U}\bar{U}\bar{q}$), ($\bar{U}\bar{U}\bar{U}$) can exist [8, 14, 15]. Formation of these double and triple states at accelerators and in cosmic rays is strongly sup-

pressed, but they can form in early Universe and strongly influence cosmological evolution of 4th generation hadrons. As shown in [10], anti- U-triple state called anutium or $\Delta_{3\bar{U}}^{--}$ is of special interest. This stable anti- Δ -isobar, composed of \bar{U} antiquarks is bound with ${}^4\text{He}$ in atom-like state of O-helium [10] or ANO-helium [11, 12, 13], proposed as dominant forms of dark matter.

2.4 Problems of composite dark matter scenarios

In all these recent models, the predicted stable charged particles escape experimental discovery, because they are hidden in elusive atoms, composing the dark matter of the modern Universe. It offers a new solution for the physical nature of the cosmological dark matter. As it was recently shown in [20] such a solution is also possible in the framework of walking technicolor models [21, 22, 23, 24, 25, 26] and can be realized without an *ad hoc* assumption on charged particle excess, made in the approaches (a)-(c).

The approaches (b) and (c) try to escape the problems of free charged dark matter particles [29] by hiding opposite-charged particles in atom-like bound systems, which interact weakly with baryonic matter. However, in the case of charge symmetry, when primordial abundances of particles and antiparticles are equal, annihilation in the early Universe suppresses their concentration. If this primordial abundance still permits these particles and antiparticles to be the dominant dark matter, the explosive nature of such dark matter is ruled out by constraints on the products of annihilation in the modern Universe [8, 18]. Even in the case of charge asymmetry with primordial particle excess, when there is no annihilation in the modern Universe, binding of positive and negative charge particles is never complete and positively charged heavy species should retain. Recombining with ordinary electrons, these heavy positive species give rise to cosmological abundance of anomalous isotopes, exceeding experimental upper limits. To satisfy these upper limits, the anomalous isotope abundance on Earth should be reduced, and the mechanisms for such a reduction are accompanied by effects of energy release which are strongly constrained, in particular, by the data from large volume detectors.

These problems of composite dark matter models [14, 16] revealed in [8, 15, 18, 10], can be avoided, if the excess of only -2 charge A^{--} particles is generated in the early Universe. In walking technicolor models, technilepton and technibaryon excess is related to baryon excess and the excess of -2 charged particles can appear naturally for a reasonable choice of model parameters [20]. It distinguishes this case from other composite dark matter models, since in all the previous realizations, starting from [14], such an

excess was put by hand to saturate the observed cold dark matter (CDM) density by composite dark matter. Taking into account that the earlier scenarios were recently extensively reviewed in [13], we'll concentrate further on the scenario [20], based on the walking technicolor model.

3 Dark Matter from Walking Technicolor

The minimal walking technicolor model [21, 22, 23, 24, 25, 26] has two techniquarks, i.e. up U and down D , that transform under the adjoint representation of an $SU(2)$ technicolor gauge group. The global symmetry of the model is an $SU(4)$ that breaks spontaneously to an $SO(4)$. The chiral condensate of the techniquarks breaks the electroweak symmetry. There are nine Goldstone bosons emerging from the symmetry breaking. Three of them are eaten by the W and the Z bosons. The remaining six Goldstone bosons are UU , UD , DD and their corresponding antiparticles. These six Goldstone bosons carry technibaryon number since they are made of two techniquarks or two anti-techniquarks. This means that if no processes violate the technibaryon number, the lightest technibaryon will be stable.

The electric charges of UU , UD , and DD are given in general by $y + 1$, y , and $y - 1$ respectively, where y is an arbitrary real number. For any real value of y , gauge anomalies are canceled [26]. The model requires in addition the existence of a fourth family of leptons, i.e. a “new neutrino” ν' and a “new electron” ζ in order to cancel the Witten global anomaly. Their electric charges are in terms of y respectively $(1 - 3y)/2$ and $(-1 - 3y)/2$. The effective theory of this minimal walking technicolor model has been presented in [25, 30].

There are several possibilities for a dark matter candidate emerging from this minimal walking technicolor model. For the case where $y = 1$, the D techniquark (and therefore also the DD boson) become electrically neutral. If one assumes that DD is the lightest technibaryon, then it is absolutely stable, because there is no way to violate the technibaryon number apart from the sphalerons that freeze out close to the electroweak scale. This scenario was studied in Refs. [25, 26].

Within the same model and electric charge assignment, there is another possibility. Since both techniquarks and technigluons transform under the adjoint representation of the $SU(2)$ group, it is possible to have bound states between a D and a technigluon G . The object $D^\alpha G^\alpha$ (where α denotes technicolor states) is techni-colorless. If such an object has a Majorana mass, then it can account for the whole dark matter density without being excluded

by CDMS, due to the fact that Majorana particles have no spin independent interaction with nuclei and their non-coherent elastic cross section is very low for the current sensitivity of detectors [31].

Finally, if one choose $y = 1/3$, ν' has zero electric charge. In this case the heavy fourth Majorana neutrino ν' can play the role of a dark matter particle. This scenario was explored first in [32] and later in [31]. It was shown that indeed the fourth heavy neutrino can provide the dark matter density without being excluded by CDMS [33] or any other experiment.

Scenario of composite dark matter corresponds mostly the first case mentioned above, that is $y = 1$ and the Goldstone bosons UU , UD , and DD have electric charges 2, 1, and 0 respectively. In addition for $y = 1$, the electric charges of ν' and ζ are respectively -1 and -2 . There are three possibilities for a scenario where stable particles with -2 electric charge have substantial relic densities and can capture ${}^4\text{He}^{++}$ nuclei to form a neutral atom.

The first one is to have a relic density of $\bar{U}\bar{U}$, which has -2 charge. For this to be true we should assume that UU is lighter than UD and DD and no processes (apart from electroweak sphalerons) violate the technibaryon number. The second one is to have abundance of ζ that again has -2 charge and the third case is to have both $\bar{U}\bar{U}$ (or DD or $\bar{D}\bar{D}$) and ζ .

For the first case to be realized, UU although charged, should be lighter than both UD and DD . This can happen if one assumes that there is an isospin splitting between U and D . This is not hard to imagine since for the same reason in QCD the charged proton is lighter than the neutral neutron. Upon making this assumption, UD and DD will decay through weak interactions to the lightest UU . The technibaryon number TB is conserved and therefore UU (or $\bar{U}\bar{U}$) is stable.

Similarly in the second case where ζ is the abundant -2 charge particle, ζ must be lighter than ν' and there should be no mixing between the fourth family of leptons and the other three of the Standard Model. The technilepton number L' number is violated only by sphalerons and therefore after the temperature falls roughly below the electroweak scale Λ_{EW} and the sphalerons freeze out, L' is conserved, which means that the lightest particle, that is ζ in this case, is absolutely stable. It was also assumed in [20] that technibaryons decay to Standard Model particles through Extended Technicolor (ETC) interactions and therefore $TB = 0$.

Finally there is a possibility to have both the L' and TB conserved after sphalerons have frozen out. In this case, the dark matter would be composed of bound atoms (${}^4\text{He}^{++}\zeta^{--}$) and either (${}^4\text{He}^{++}(\bar{U}\bar{U})^{--}$) or neutral DD (or $\bar{D}\bar{D}$).

4 The origin of Techni-O-helium

4.1 Techniparticle excess

The calculation of the excess of the technibaryons with respect to the one of the baryons was pioneered in Refs. [34, 35, 36, 37]. In [20] the excess of $\bar{U}\bar{U}$ and ζ was calculated along the lines of [26]. The technicolor and the Standard Model particles are in thermal equilibrium as long as the rate of the weak (and color) interactions is larger than the expansion of the Universe. In addition, the sphalerons allow the violation TB , baryon number B , lepton number L , and L' as long as the temperature of the Universe is higher than roughly Λ_{EW} . It is possible through the equations of thermal equilibrium, sphalerons and overall electric neutrality for the particles of the Universe, to associate the chemical potentials of the various particles. The relationship between these chemical potentials with proper account for statistical factors, σ , results in relationship between TB , B , L , and L' after sphaleron processes are frozen out [20]

$$\frac{TB}{B} = -\sigma_{UU} \left(\frac{L'}{B} \frac{1}{3\sigma_\zeta} + 1 + \frac{L}{3B} \right). \quad (1)$$

Here σ_i ($i = UU, \zeta$) are statistical factors. It was shown in [20] that there can be excess of techni(anti)baryons, $(\bar{U}\bar{U})^{--}$, technileptons ζ^{--} or of the both and parameters of model were found at which this asymmetry has proper sign and value, saturating the dark matter density at the observed baryon asymmetry of the Universe.

4.2 Formation of techni-O-helium

In the Standard Big Bang nucleosynthesis (SBBN), 4He is formed with an abundance $r_{He} = 0.1r_B = 8 \cdot 10^{-12}$ and, being in excess, binds all the negatively charged techni-species into atom-like systems.

At a temperature $T < I_o = Z_{TC}^2 Z_{He}^2 \alpha^2 m_{He}/2 \approx 1.6 \text{ MeV}$, where α is the fine structure constant, and $Z_{TC} = -2$ stands for the electric charge of $\bar{U}\bar{U}$ and/or of ζ , the reaction

$$\zeta^{--} + {}^4He^{++} \rightarrow \gamma + ({}^4He\zeta) \quad (2)$$

and/or

$$(\bar{U}\bar{U})^{--} + {}^4He^{++} \rightarrow \gamma + ({}^4He(\bar{U}\bar{U})) \quad (3)$$

can take place. Actually they can go only after ${}^4\text{He}$ is formed in SBBN at $T \leq 100\text{ keV}$. In these reactions neutral techni-O-helium “atoms” are produced at $T_o \approx 60\text{ keV}$ [20]. The size of these “atoms” is [10, 18, 20]

$$R_o \sim 1/(Z_{TC}Z_{He}\alpha m_{He}) \approx 2 \cdot 10^{-13}\text{ cm}. \quad (4)$$

Virtually all the free $(\bar{U}\bar{U})$ and/or ζ (which will be further denoted by A^{--}) are trapped by helium and their remaining abundance becomes exponentially small.

For particles Q^- with charge -1 , as for tera-electrons in the sinister model [14], ${}^4\text{He}$ trapping results in the formation of a positively charged ion $({}^4\text{He}^{++}Q^-)^+$, result in dramatic over-production of anomalous hydrogen [15]. Therefore, only the choice of -2 electric charge for stable techniparticles makes it possible to avoid this problem. In this case, ${}^4\text{He}$ trapping leads to the formation of neutral *techni-O-helium* “atoms” $({}^4\text{He}^{++}A^{--})$.

The formation of techni-O-helium reserves a fraction of ${}^4\text{He}$ and thus it changes the primordial abundance of ${}^4\text{He}$. For the lightest possible masses of the techniparticles $m_\zeta \sim m_{TB} \sim 100\text{ GeV}$, this effect can reach 50% of the ${}^4\text{He}$ abundance formed in SBBN. Even if the mass of the techniparticles is of the order of TeV, 5% of the ${}^4\text{He}$ abundance is hidden in the techni-O-helium atoms. This can lead to important consequences once we compare the SBBN theoretical predictions to observations.

4.3 Techni-O-helium in Big bang Nucleosynthesis

The question of the participation of techni-O-helium in nuclear transformations and its direct influence on the chemical element production is less evident. Indeed, techni-O-helium looks like an α particle with a shielded electric charge. It can closely approach nuclei due to the absence of a Coulomb barrier. Because of this, in the presence of techni-O-helium, the character of SBBN processes should change drastically. However, it might not lead to immediate contradiction with observations.

The following simple argument [18, 20] can be used for suppression of binding of A^{--} with nuclei heavier than ${}^4\text{He}$. In fact, the size of techni-O-helium is of the order of the size of ${}^4\text{He}$ and for a nucleus A_ZQ with electric charge $Z > 2$, the size of the Bohr orbit for an QA^{--} ion is less than the size of the nucleus A_ZQ (see [38]). This means that while binding with a heavy nucleus, A^{--} penetrates it and interacts effectively with a part of the nucleus of a size less than the corresponding Bohr orbit. This size corresponds to the size of ${}^4\text{He}$, making techni-O-helium the most bound QA^{--} atomic state. It favors a picture, according to which a techni-O-helium collision with a

nucleus, results in the formation of techni-O-helium and the whole process looks like an elastic collision.

The interaction of the 4He component of $(He^{++}A^{--})$ with a A_ZQ nucleus can lead to a nuclear transformation due to the reaction

$${}^A_ZQ + (HeA) \rightarrow {}^{A+4}_{Z+2}Q + A^{--}, \quad (5)$$

provided that the masses of the initial and final nuclei satisfy the energy condition

$$M(A, Z) + M(4, 2) - I_o > M(A + 4, Z + 2), \quad (6)$$

where $I_o = 1.6 \text{ MeV}$ is the binding energy of techni-O-helium and $M(4, 2)$ is the mass of the 4He nucleus.

This condition is not valid for stable nuclei participating in reactions of the SBBN. However, tritium 3H , which is also formed in SBBN with abundance ${}^3H/H \sim 10^{-7}$ satisfies this condition and can react with techni-O-helium, forming 7Li and opening the path of successive techni-O-helium catalyzed transformations to heavy nuclei. This effect might strongly influence the chemical evolution of matter on the pre-galactic stage and needs a self-consistent consideration within the Big Bang nucleosynthesis network. However, the following arguments [18, 20] show that this effect may not lead to immediate contradiction with observations as it might be expected.

- On the path of reactions (5), the final nucleus can be formed in the excited $(\alpha, M(A, Z))$ state, which can rapidly experience an α -decay, giving rise to techni-O-helium regeneration and to an effective quasi-elastic process of $({}^4He^{++}A^{--})$ -nucleus scattering. It leads to a possible suppression of the techni-O-helium catalysis of nuclear transformations.
- The path of reactions (5) does not stop on 7Li but goes further through ${}^{11}B$, ${}^{15}N$, ${}^{19}F$, ... along the table of the chemical elements.
- The cross section of reactions (5) grows with the mass of the nucleus, making the formation of the heavier elements more probable and moving the main output away from a potentially dangerous Li and B overproduction.

Such a qualitative change of the physical picture appeals to necessity in a detailed nuclear physics treatment of the $(A^{--} + \text{nucleus})$ systems and of the whole set of transformations induced by techni-O-helium. Though the above arguments do not seem to make these dangers immediate and obvious, a detailed study of this complicated problem is needed.

5 Techni-O-helium Universe

5.1 Gravitational instability of the techni-O-helium gas

Due to nuclear interactions of its helium constituent with nuclei in cosmic plasma, the techni-O-helium gas is in thermal equilibrium with plasma and radiation on the Radiation Dominance (RD) stage, and the energy and momentum transfer from the plasma is effective. The radiation pressure acting on plasma is then effectively transferred to density fluctuations of techni-O-helium gas and transforms them in acoustic waves at scales up to the size of the horizon. However, as it was first noticed in [10], this transfer to heavy nuclear-interacting species becomes ineffective before the end of the RD stage and such species decouple from plasma and radiation. Consequently, nothing prevents the development of gravitational instability in the gas of these species. This argument is completely applicable to the case of techni-O-helium.

At temperature $T < T_{od} \approx 45S_2^{2/3}$ eV, first estimated in [10] for the case of OLe-helium, the energy and momentum transfer from baryons to techni-O-helium is not effective because $n_B \langle \sigma v \rangle (m_p/m_o)t < 1$, where m_o is the mass of the $tOHe$ atom and $S_2 = \frac{m_o}{100 \text{ GeV}}$. Here

$$\sigma \approx \sigma_o \sim \pi R_o^2 \approx 10^{-25} \text{ cm}^2, \quad (7)$$

and $v = \sqrt{2T/m_p}$ is the baryon thermal velocity. The techni-O-helium gas decouples from the plasma and plays the role of dark matter, which starts to dominate in the Universe at $T_{RM} = 1$ eV.

The development of gravitational instabilities of the techni-O-helium gas triggers large scale structure formation, and the composite nature of techni-O-helium makes it more close to warm dark matter.

The total mass of the $tOHe$ gas with density $\rho_d = \frac{T_{RM}}{T_{od}} \rho_{tot}$ within the cosmological horizon $l_h = t$ is

$$M = \frac{4\pi}{3} \rho_d t^3.$$

In the period of decoupling $T = T_{od}$, this mass depends strongly on the techniparticle mass S_2 and is given by

$$M_{od} = \frac{T_{RM}}{T_{od}} m_{Pl} \left(\frac{m_{Pl}}{T_{od}} \right)^2 \approx 2 \cdot 10^{46} S_2^{-8/3} \text{ g} = 10^{13} S_2^{-8/3} M_\odot, \quad (8)$$

where M_\odot is the solar mass. The techni-O-helium is formed only at $T_o \approx 60$ keV and its total mass within the cosmological horizon in the period of

its creation is

$$M_o = \frac{T_{RM}}{T_o} m_{Pl} \left(\frac{m_{Pl}}{T_o} \right)^2 = M_{od} \left(\frac{T_o}{T_{od}} \right)^3 = 10^{37} \text{ g}$$

On the RD stage before decoupling, the Jeans length λ_J of the $tOHe$ gas was of the order of the cosmological horizon $\lambda_J \sim l_h \sim t$. After decoupling at $T = T_{od}$, it falls down to $\lambda_J \sim v_o t$, where $v_o = \sqrt{2T_{od}/m_o}$. Though after decoupling the Jeans mass in the $tOHe$ gas correspondingly falls down [10, 20]

$$M_J \sim v_o^3 M_{od} \sim 3 \cdot 10^{-14} M_{od},$$

one should expect strong suppression of fluctuations on scales $M < M_o$, as well as adiabatic damping of sound waves in the RD plasma for scales $M_o < M < M_{od}$. It provides suppression of small scale structure in the considered model for all reasonable masses of techniparticles.

The cross section of mutual collisions of techni-O-helium “atoms” is given by Eq. (7). The $tOHe$ “atoms” can be considered as collision-less gas in clouds with a number density n_o and a size R , if $n_o R < 1/\sigma_o$. This condition is valid for the techni-O-helium gas in galaxies.

Mutual collisions of techni-O-helium “atoms” determine the evolution timescale for a gravitationally bound system of collision-less $tOHe$ gas

$$t_{ev} = 1/(n\sigma_o v) \approx 2 \cdot 10^{20} (1 \text{ cm}^{-3}/n)^{7/6} \text{ s},$$

where the relative velocity $v = \sqrt{GM/R}$ is taken for a cloud of mass M_o and an internal number density n . This timescale exceeds substantially the age of the Universe and the internal evolution of techni-O-helium clouds cannot lead to the formation of dense objects. Being decoupled from baryonic matter, the $tOHe$ gas does not follow the formation of baryonic astrophysical objects (stars, planets, molecular clouds...) and forms dark matter halos of galaxies.

5.2 Techniparticle component of cosmic rays

The nuclear interaction of techni-O-helium with cosmic rays gives rise to ionization of this bound state in the interstellar gas and to acceleration of free techniparticles in the Galaxy. During the lifetime of the Galaxy $t_G \approx 3 \cdot 10^{17} \text{ s}$, the integral flux of cosmic rays

$$F(E > E_0) \approx 1 \cdot \left(\frac{E_0}{1 \text{ GeV}} \right)^{-1.7} \text{ cm}^{-2} \text{ s}^{-1}$$

can disrupt the fraction of galactic techni-O-helium $\sim F(E > E_{min})\sigma_o t_G \leq 10^{-3}$, where we took $E_{min} \sim I_o$. Assuming a universal mechanism of cosmic ray acceleration, a universal form of their spectrum, taking into account that the ${}^4\text{He}$ component corresponds to $\sim 5\%$ of the proton spectrum, and that the spectrum is usually reduced to the energy per nucleon, the -2 charged techniparticle component with anomalously low Z/A can be present in cosmic rays at a level of

$$\frac{A^{--}}{\text{He}} \geq 3 \cdot 10^{-7} \cdot S_2^{-3.7}. \quad (9)$$

This flux may be within the reach for PAMELA and AMS02 cosmic ray experiments.

Recombination of free techniparticles with protons and nuclei in the interstellar space can give rise to radiation in the range from few tens of keV - 1 MeV. However such a radiation is below the cosmic nonthermal electromagnetic background radiation observed in this range.

5.3 Effects of techni-O-helium catalyzed processes in the Earth

The first evident consequence of the proposed excess is the inevitable presence of $tOHe$ in terrestrial matter. This is because terrestrial matter appears opaque to $tOHe$ and stores all its in-falling flux.

If the $tOHe$ capture by nuclei is not effective, its diffusion in matter is determined by elastic collisions, which have a transport cross section per nucleon

$$\sigma_{tr} = \pi R_o^2 \frac{m_p}{m_o} \approx 10^{-27} / S_2 \text{ cm}^2. \quad (10)$$

In atmosphere, with effective height $L_{atm} = 10^6 \text{ cm}$ and baryon number density $n_B = 6 \cdot 10^{20} \text{ cm}^{-3}$, the opacity condition $n_B \sigma_{tr} L_{atm} = 6 \cdot 10^{-1} / S_2$ is not strong enough. Therefore, the in-falling $tOHe$ particles are effectively slowed down only after they fall down terrestrial surface in $16 S_2$ meters of water (or $4 S_2$ meters of rock). Then they drift with velocity $V = \frac{g}{n\sigma v} \approx 8 S_2 A^{1/2} \text{ cm/s}$ (where $A \sim 30$ is the average atomic weight in terrestrial surface matter, and $g = 980 \text{ cm/s}^2$), sinking down the center of the Earth on a timescale $t = R_E / V \approx 1.5 \cdot 10^7 S_2^{-1} \text{ s}$, where R_E is the radius of the Earth.

The in-falling techni-O-helium flux from dark matter halo is $\mathcal{F} = n_o v_h / 8\pi$, where the number density of $tOHe$ in the vicinity of the Solar System is $n_o = 3 \cdot 10^{-3} S_2^{-1} \text{ cm}^{-3}$ and the averaged velocity $v_h \approx 3 \cdot 10^7 \text{ cm/s}$. During the

lifetime of the Earth ($t_E \approx 10^{17}$ s), about $2 \cdot 10^{38} S_2^{-1}$ techni-O-helium atoms were captured. If $tOHe$ dominantly sinks down the Earth, it should be concentrated near the Earth's center within a radius $R_{oc} \sim \sqrt{3T_c/(m_o 4\pi G \rho_c)}$, which is $\leq 10^8 S_2^{-1/2}$ cm, for the Earth's central temperature $T_c \sim 10^4$ K and density $\rho_c \sim 4$ g/cm³.

Near the Earth's surface, the techni-O-helium abundance is determined by the equilibrium between the in-falling and down-drifting fluxes. It gives

$$n_{oE} = 2\pi\mathcal{F}/V = 3 \cdot 10^3 \cdot S_2^{-2} \cdot A^{-1/2} \text{ cm}^{-3},$$

or for $A \sim 30$ about $5 \cdot 10^2 \cdot S_2^{-2} \text{ cm}^{-3}$. This number density corresponds to the fraction

$$f_{oE} \sim 5 \cdot 10^{-21} \cdot S_2^{-2}$$

relative to the number density of the terrestrial atoms $n_A \approx 10^{23} \text{ cm}^{-3}$.

These neutral (${}^4He^{++}A^{--}$) “atoms” may provide a catalysis of cold nuclear reactions in ordinary matter (much more effectively than muon catalysis). This effect needs a special and thorough investigation. On the other hand, if A^{--} capture by nuclei, heavier than helium, is not effective and does not lead to a copious production of anomalous isotopes, the (${}^4He^{++}A^{--}$) diffusion in matter is determined by the elastic collision cross section (10) and may effectively hide techni-O-helium from observations.

One can give the following argument for an effective regeneration and quasi-elastic collisions of techni-O-helium in terrestrial matter. The techni-O-helium can be destroyed in the reactions (5). Then, free A^{--} are released and due to a hybrid Auger effect (capture of A^{--} , ejection of ordinary e from the atom with atomic number A , and charge of the nucleus Z), A^{--} -atoms are formed, in which A^{--} occupies highly an excited level of the (A_ZQA) system, which is still much deeper than the lowest electronic shell of the considered atom. The (A_ZQA) atomic transitions to lower-lying states cause radiation in the intermediate range between atomic and nuclear transitions. In course of this falling down to the center of the ($Z - A^{--}$) system, the nucleus approaches A^{--} . For $A > 3$ the energy of the lowest state n (given by $E_n = \frac{M\tilde{\alpha}^2}{2n^2} = \frac{2Am_p Z^2 \alpha^2}{n^2}$) of the ($Z - A^{--}$) system (having reduced mass $M \approx Am_p$) with a Bohr orbit $r_n = \frac{n}{M\tilde{\alpha}} = \frac{n}{2AZm_p\alpha}$, exceeding the size of the nucleus $r_A \sim A^{1/3}m_\pi^{-1}$ (m_π being the mass of the pion), is less than the binding energy of $tOHe$. Therefore the regeneration of techni-O-helium in a reaction, inverse to (5), takes place. An additional reason for the domination of the elastic channel of the reactions (5) is that the final state nucleus is created in the excited state and its de-excitation via α -decay can also result

in techni-O-helium regeneration. If regeneration is not effective and A^{--} remains bound to the heavy nucleus, anomalous isotope of $Z - 2$ element should appear. This is a serious problem for the considered model.

However, if the general picture of sinking down is valid, it might give no more than the ratio $f_{oE} \sim 5 \cdot 10^{-21} \cdot S_2^{-2}$ of number density of anomalous isotopes to the number density of atoms of terrestrial matter around us, which is below the experimental upper limits for elements with $Z \geq 2$. For comparison, the best upper limits on the anomalous helium were obtained in [39]. It was found, by searching with the use of laser spectroscopy for a heavy helium isotope in the Earth's atmosphere, that in the mass range 5 GeV - 10000 GeV, the terrestrial abundance (the ratio of anomalous helium number to the total number of atoms in the Earth) of anomalous helium is less than $2 \cdot 10^{-19} - 3 \cdot 10^{-19}$.

5.4 Direct search for techni-O-helium

It should be noted that the nuclear cross section of the techni-O-helium interaction with matter escapes the severe constraints [40] on strongly interacting dark matter particles (SIMPs) [41, 40] imposed by the XQC experiment [42].

In underground detectors, $tOHe$ “atoms” are slowed down to thermal energies and give rise to energy transfer $\sim 2.5 \cdot 10^{-3} \text{ eV} A/S_2$, far below the threshold for direct dark matter detection. It makes this form of dark matter insensitive to the CDMS constraints. However, $tOHe$ induced nuclear transformation can result in observable effects.

Therefore, a special strategy of such a search is needed, that can exploit sensitive dark matter detectors on the ground or in space. In particular, as it was revealed in [44], a few g of superfluid 3He detector [43], situated in ground-based laboratory can be used to put constraints on the in-falling techni-O-helium flux from the galactic halo.

6 Discussion

To conclude, the existence of heavy stable particles is one of the popular solutions for dark matter problem. If stable particles have electric charge, dark matter candidates can be atom-like states, in which negatively and positively charged particles are bound by Coulomb attraction. In this case there is a serious problem to prevent overproduction of accompanying anomalous forms of atomic matter.

Indeed, recombination of charged species is never complete in the expanding Universe, and significant fraction of free charged particles should

remain unbound. Free positively charged species behave as nuclei of anomalous isotopes, giving rise to a danger of their over-production. Moreover, as soon as ${}^4\text{He}$ is formed in Big Bang nucleosynthesis it captures all the free negatively charged heavy particles. If the charge of such particles is -1 (as it is the case for tera-electron in [14]) positively charged ion $({}^4\text{He}^{++}E^-)^+$ puts Coulomb barrier for any successive decrease of abundance of species, over-polluting modern Universe by anomalous isotopes. It excludes the possibility of composite dark matter with -1 charged constituents and only -2 charged constituents avoid these troubles, being trapped by helium in neutral OLe-helium, O-helium (ANO-helium) or techni-O-helium states.

The existence of -2 charged states and the absence of stable -1 charged constituents can take place in AC-model, in charge asymmetric model of 4th generation and walking technicolor model with stable doubly charged technibaryons and/or technileptons.

To avoid overproduction of anomalous isotopes, an excess of -2 charged particles over their antiparticles should be generated in the Universe. In all the earlier realizations of composite dark matter scenario, this excess was put by hand to saturate the observed dark matter density. In walking technicolor model this abundance of -2 charged techibaryons and/or technileptons is connected naturally to the value and sign of cosmological baryon asymmetry. These doubly charged A^{--} techniparticles bind with ${}^4\text{He}$ in the neutral techni-O-helium states. For reasonable values of the techniparticle mass, the amount of primordial ${}^4\text{He}$, bound in this atom like state is significant and should be taken into account in comparison to observations.

A challenging problem is the nuclear transformations, catalyzed by techni-O-helium. The question about their consistency with observations remains open, since special nuclear physics analysis is needed to reveal what are the actual techni-O-helium effects in SBBN and in terrestrial matter. However, qualitatively one can expect a path for O-helium catalysis of heavy elements, making primordial heavy elements a signature for composite dark matter scenarios.

The destruction of techni-O-helium by cosmic rays in the Galaxy releases free charged techniparticles, which can be accelerated and contribute to the flux of cosmic rays. In this context, the search for techniparticles at accelerators and in cosmic rays acquires the meaning of a crucial test for the existence of the basic components of the composite dark matter. At accelerators, techniparticles would look like stable doubly charged heavy leptons, while in cosmic rays, they represent a heavy -2 charge component with anomalously low ratio of electric charge to mass.

The presented arguments enrich the class of possible particles, which

can follow from extensions of the Standard Model and be considered as dark matter candidates. One can extend the generally accepted viewpoint that new stable particles should be neutral and weakly interacting. We have seen that they can also be charged and play the role of dark matter because they are hidden in atom-like states, which are not the source of visible light. The constraints on such particles are very strict and open a very narrow window for this new cosmologically interesting degree of freedom in particle theory. However, taking into account the exciting ability of O-helium to catalyze nuclear transformations of chemical elements, it is hard to estimate the expectation value of its discovery.

Acknowledgements

I am grateful to co-authors K.Belotsky, C. Kouvaris, K.Shibaev and C. Stephan for fruitful collaboration in obtaining the presented results.

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